# East Goose and West Goose Lakes (and Oak Knoll Pond) In-Lake Treatment Feasibility Study

Prepared for
Vadnais Lake Area Water Management Organization (VLAWMO)

August, 2018

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## August, 2018

# Contents

## List of Tables

## List of Figures

# 1.0 Project Background and Purpose

Barr Engineering Company (Barr) was retained by Vadnais Lake Area Water Management Organization (VLAWMO) to provide engineering services to build on past efforts (Barr, 2017) by completing sediment monitoring and aluminum sulfate (alum) dosing for East and West Goose Lake, and optionally, Oak Knoll Pond to improve the lake/pond and downstream lake water quality. This feasibility study includes sediment core collection/analysis, determination of an alum dosage plan, and compilation/consolidation of supporting information for a BWSR grant application to complete in-lake management practices.

Figure 1-1 shows the topography, watershed divides and drainage patterns for East and West Goose Lakes while the same information, including subcatchments and monitoring stations. Table 1-1 shows the lake morphology/depth and other watershed/water body characteristics for each basin (as published in the TMDL report).

**Table 1-1 Lake Morphology and Watershed Characteristics**

| Parameter | East Goose Lake | West Goose Lake |
|---|---|---|
| Surface Area (acres) | 116 | 24 |
| Average Depth (feet) | 5.5 | 4.4 |
| Maximum Depth (feet) | 9 | 7 |
| Residence Time (years) | 2.3 | 0.3 |
| Direct Drainage Area (acres) | 578 | 239 |

## 1.1 Summary of Lake TMDLs and Past Studies

In preparing for a stakeholder charrette (Barr, 2017), the Barr/Young Environmental team systematically reviewed reports and data collected on Goose Lake and Wilkinson Lake, including the total maximum daily load (TMDL) report and implementation plan (2014), sustainable lake management plans (2014 updated in 2017), storm sewer and treatment practice plans, proposed redevelopment plans, fish (2012 & 2017) and aquatic plant survey reports (2010 & 2014), bathymetric surveys and internal loading analyses (2010, 2015). Through the stakeholder participation process and personal communications we also became more aware of the potential for boating impacts on water quality changes in the Goose Lake.

EAST AND WEST
GOOSE LAKE WATERSHED
Vadnais Lakes Area
Watershed Management
Organization

FIGURE 1-1

The TMDL report (Wenck, 2014a) and implementation plan (VLAWMO, 2014) estimated internal and watershed loading and called for the following total phosphorus load reductions for the respective lakes:

- 91% reduction for East Goose Lake—corresponds to 96% reduction of internal load and 63% reduction from stormwater runoff or 88% of current loading is internal and 11% from the watershed
- 70% reduction for West Goose Lake—corresponds to 71% reduction of internal load, 77% reduction from East Goose Lake and 86% reduction from stormwater runoff or 82% of current loading is internal or coming from E. Goose and 15% of the load coming from the watershed.

The high percentage of internal loading on both lakes has focused the direction additional studies since the publishing of the TMDL report. This included increased monitoring, several sediment studies and updated fish and vegetation studies.

Anoxic sediment phosphorus release rates determined from laboratory experiments on Goose Lake cores (James, 2010 and Wenck, 2014b) were approximately an order of magnitude lower than the release rates used for the lake water quality modeling in the TMDL study. The difference in internal load was attributed to resuspension associated with motor boat activity (Wenck, 2014a). A subsequent study (UW Stout and Wenck, 2015) of sediment resuspension as a potential phosphorus source indicated that Goose Lake sediment has a high potential for resuspension (due to its particulate size and specific gravity characteristics), but does not release or desorb phosphorus and plays a minor role in contributing bioavailable phosphorus to the lake.

Lake and watershed modeling, along with the associated GIS mapping, from the TMDL study were obtained and reviewed for use in the most recent feasibility analysis. Additional concerns with the TMDL modeling are discussed in Section 2.1, in which it was determined that the following data gaps and limitations of the past analyses would also need to be addressed to better evaluate the sources of phosphorus during the critical condition and potential improvement options for the respective study lakes:

- The P8 watershed modeling from the TMDL study did not simulate the existing Best Management Practices (BMPs) in the West and East Goose Lake watersheds. As discussed in Section 2, this may have led to overestimated phosphorus loadings for each watershed in the TMDL study.
- The GIS mapping (and associated P8 watershed modeling) from the TMDL study included a significant landlocked area from Gem Lake in the West Goose Lake watershed. This may have also led to overestimated phosphorus loading for this watershed in the TMDL study.

VLAWMO will be further clarifying watershed loading into both basins of Goose Lake and identifying the most cost-effective best management practices utilizing the watershed based funding grant.  Barr will be updating the hydrologic and hydraulic modeling for the subwatershed, identifying and completing concept designs for three BMPs and then helping with construction oversight of the selected BMP (2018-2019).

## 1.2 Summary of Recent Water Quality Monitoring

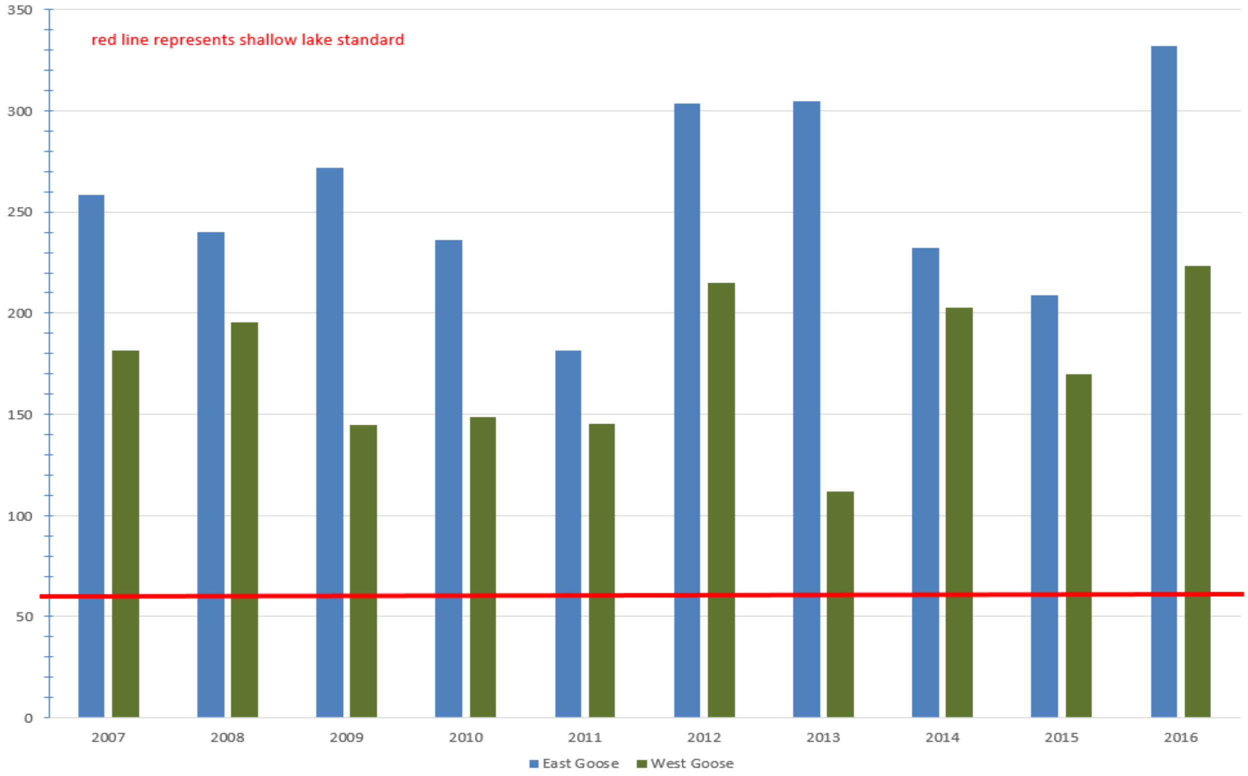
Table 1-2 shows the eleven-year summer average total phosphorus concentrations observed for each lake, as well as the average surface water concentration measured in Oak Knoll Pond during 2017. All three water bodies experience low dissolved oxygen in the bottom waters, periodically, during the summer months.

**Table 1-2 Observed Lake and Pond Water Quality**

| Water Body | Average Summer Total Phosphorus Concentration (µg/L), 2007-2017 |
|---|---|
| East Goose | 255 |
| West Goose | 175 |
| Oak Knoll Pond | 168 (2017 only) |

Figures 1-2, 1-3 and 1-4 show how the last ten years of average summer total phosphorus, chlorophyll-a and Secchi disc transparency, respectively, have varied for each lake. The first four years of the records shown in each figure represent the data used for the TMDL analyses of the respective lakes. The monitoring data shows that the lakes are not meeting any of the three shallow lake criteria during the period of record. Figure 1-2 shows that average total phosphorus concentrations were generally better for the lakes in 2011 and significantly worse in 2016. As a result, these two years became the focus of the updated lake and watershed modeling discussed in Section 2.

### Figure 1-2 Summer Average (June-Sept.) Total Phosphorus Concentrations (µg/L) since 2007



### Figure 1-3 Summer Average (June-Sept.) Chlorophyll-a Concentrations (µg/L) since 2007

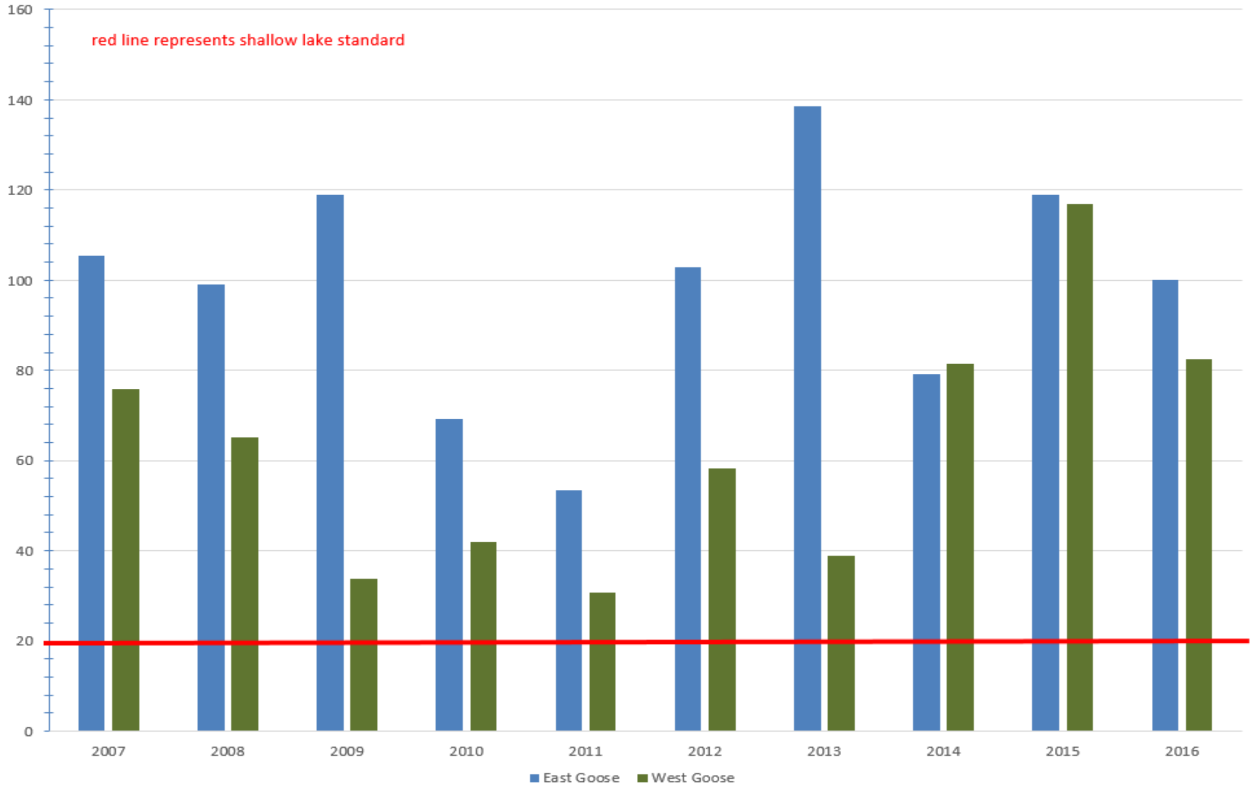


**Figure 1-4** **Summer Average (June-Sept.) Secchi Disc Transparency (meters) since 2007**

## 1.3 Current Analysis of Lake Sediment Cores

Phosphorus from stormwater over time accumulates in the bottom sediments of lakes and ponds. During the spring and fall, this phosphorus is largely tied-up and the sediments, but during the warm summer months the phosphorus can be released from bottom sediments and move upward into the water column. This can lead to summer and sometimes early fall algal blooms. Not all of the phosphorus that is incorporated into bottom sediments releases into the water column. Phosphorus in sediment is typically attached to something and can be found in the following forms (often referred to as "fractions"): calcium bound phosphorus (Ca-P), aluminum bound phosphorus (Al-P), iron bound phosphorus (Fe-P), and organically bound P (Org-P). Ca-P and Al-P are largely inert and are immobilized in the bottom sediment. Org-P decays over time and release phosphorus into the water column over the course of several years. Fe-P is the phosphorus form that readily releases into the water column during warm summer months as oxygen is depleted in the sediment.

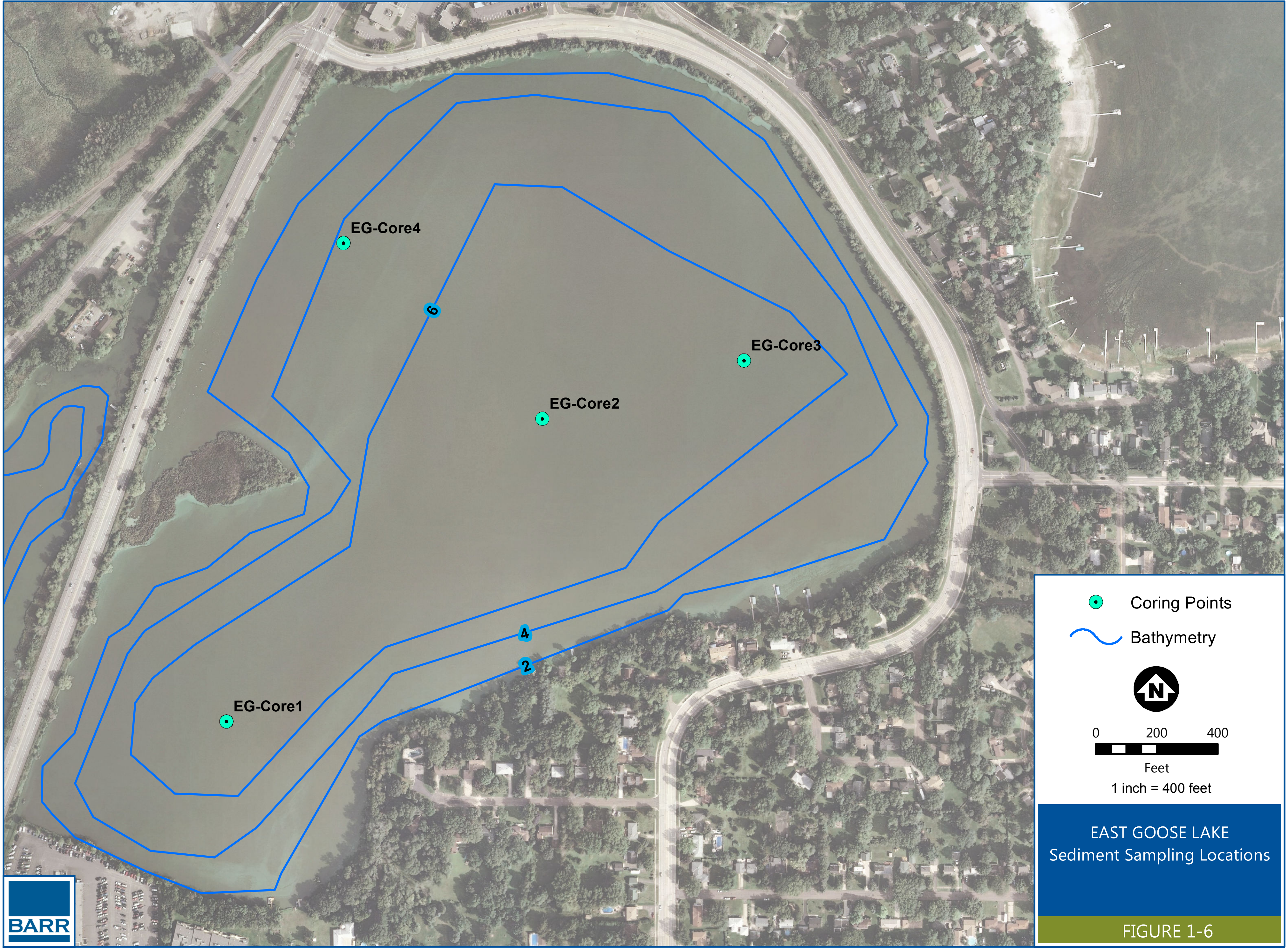
The primary purposes of collecting sediment cores is to quantify the amount of Fe-P and Org-P in sediment. The more Fe-P and Org-P in sediment the more alum will need to be applied to immobilize these phosphorus fractions. In general, aluminum treatment (either as alum or sodium aluminate, for example), forces the Fe-P to bind to aluminum and form Al-P (the inert form of aluminum). In most cases, alum treatments are designed to also provide excess aluminum in sediment which can then bind phosphorus years after the treatment. When aluminum in the form of alum or other solutions is added to a pond, it forms an aluminum hydroxide floc that settles to the lake bottom. The aluminum floc will mix into the top few to several inches of sediment over time and becomes diluted. The sediment phosphorus data collected at different depths was used to help determine the expected sediment mixing depth for each lake.

The total mass of Fe-P and Org-P in the actively mixed layers of sediment were determined for each lake. Alum doses were then calculated for each lake by determining an appropriate Al:Al-P ratio following techniques designed by Pilgrim et al. (2007).

Sediment cores were collected on October 25, 2017 in the following waterbodies: West Goose Lake (2 cores), East Goose Lake (4 cores), and Oak Knoll Pond (1 core) (see Figures 1-5, 1-6, and 1-7, respectively). Each sediment core was sliced into 2-cm sediment samples down to a depth of 10 cm, and 4 cm intervals were collected down to 18 cm or deeper. Sediment samples were returned to the Barr Engineering laboratory and analyzed for the phosphorus fractions identified previously. In general, Fe-P concentrations in the sediment of East Goose Lake and West Goose Lake were low, while organic-P was high, as shown in Figure 1-8. Phosphorus concentrations and physical characteristics were relatively similar among all four cores of East Goose Lake. The two sediment cores in West Goose Lake were also similar to one another (see Figure 1-8).

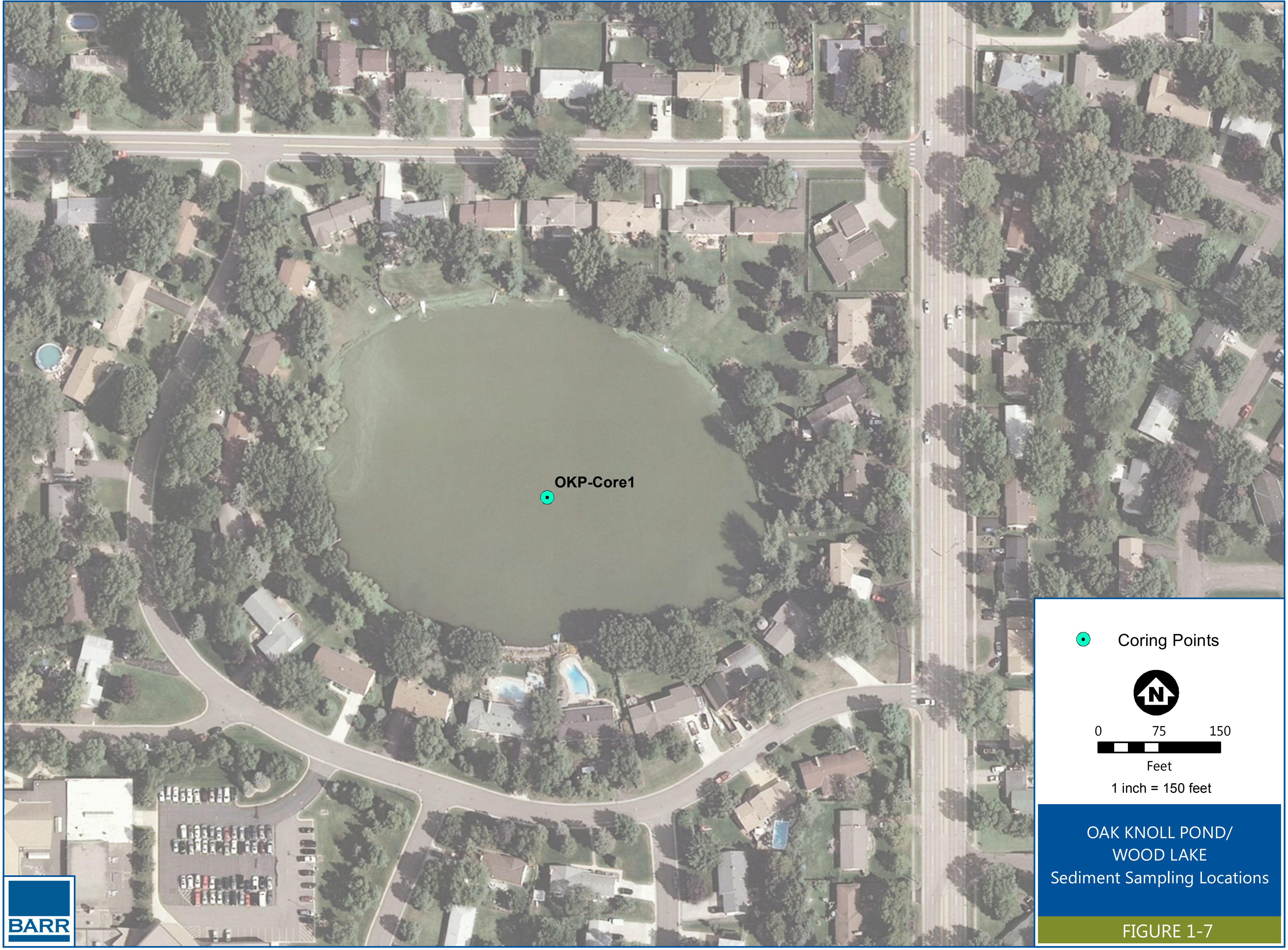
WEST GOOSE LAKE
Sediment Sampling Locations

FIGURE 1-5



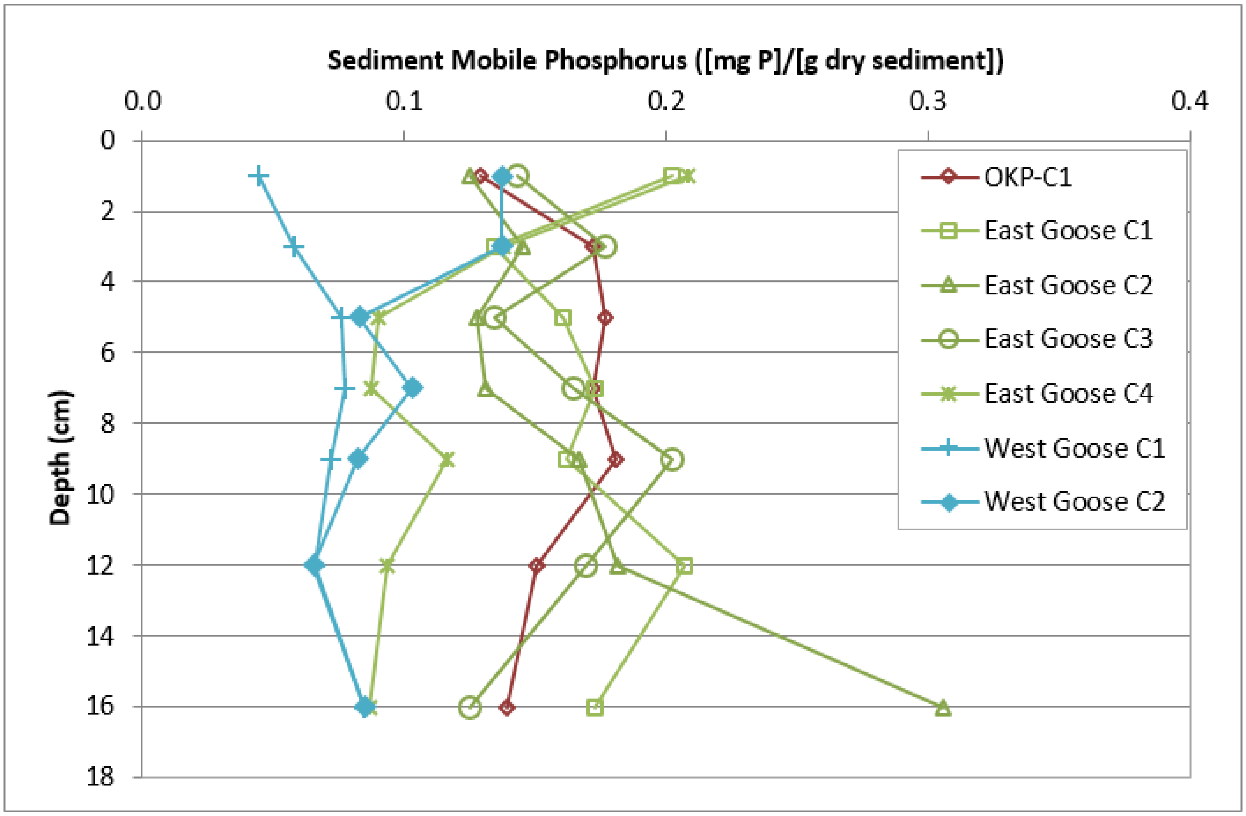
EAST GOOSE LAKE
Sediment Sampling Locations

FIGURE 1-6



OAK KNOLL POND/
WOOD LAKE
Sediment Sampling Locations

FIGURE 1-7



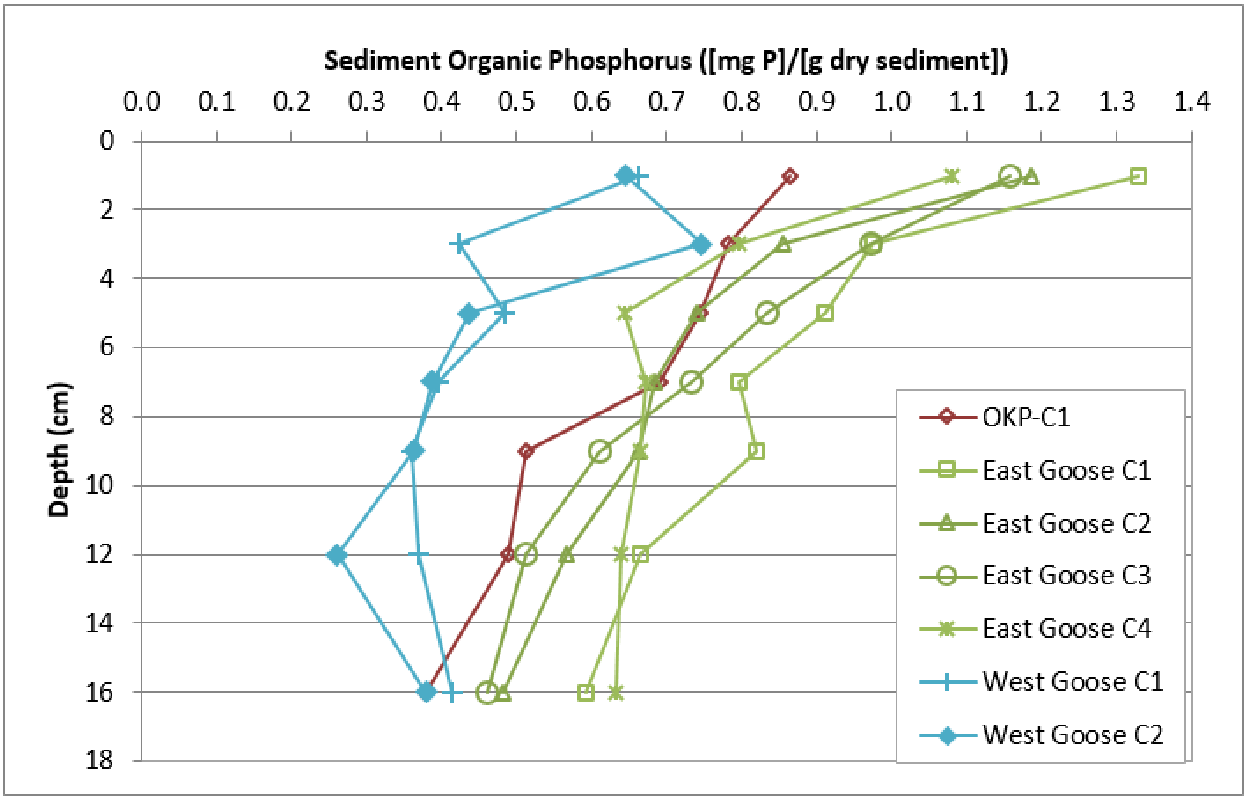


**Figure 1-8** **Results of Sediment Phosphorus Fractionations**

# 2.0 Water Quality Modeling and Analysis

A key component to performing diagnoses is selecting a rigorous approach to evaluating potential water quality benefits. The simplified lake and watershed modeling approach used in the 2014 TMDL project did not account for intra-annual variations in lake water quality was not considered for use in the previous feasibility analysis (Barr, 2017) as it lumps parameters at an annual time scale, treats lakes as fully mixed in a steady-state with uniform residence time, and does not adequately distinguish internal phosphorus loading sources from watershed sources during the critical conditions for water quality impairment. Based on our review of the available monitoring data and understanding of the purpose of the feasibility study, an approach was developed for evaluating the primary drivers of water quality impairment in each lake that adds further clarity, because it is based on updated monitoring data and accounts for intra-annual variations and recent management actions. Differentiating the individual drivers of lake water quality is based on the observed dynamics of each lake to set realistic expectations for future management actions.

The approach for this analysis used existing monitoring data, professional judgment, and modeling to identify the best approach to cost-effectively improve lake water quality. Relevant subtasks included:

- Review current and historic water chemistry and biological data. Evaluate long- and short-term water quality trends.
- Review sediment phosphorus data and use it to estimate the internal phosphorus loading potential.
- Using existing watershed modeling, develop an updated lake phosphorus balance that includes phosphorus loads from watershed and in-lake sources and evaluate results to better understand the effect of varying climatic and sensitivity to management changes.
- Analyze fish data to evaluate potential impacts of carp and black bullhead on lake water quality and to determine the impact of water quality dynamics on the fish community.
- Consider the effects that recreational boating are expected to have on lake water quality.
- Integrate data analyses from above to diagnose causes of lake water quality problems, including feedback loops and dynamics between biological measurements and lake water quality observations.
- Evaluate water quality improvement options to identify feasible and cost-effective water quality improvement options for each lake basin.
- Complete an evaluation of feasible water quality improvement options to estimate expected lake water quality changes that could be attained.

## 2.1 Existing Management Practices

### 2.1.1 Watershed Best Management Practices (BMPs)

Figure 1-1 shows the locations in the East and West Goose Lake watersheds where the city of White Bear Lake and Ramsey County have previously implemented BMPs for stormwater treatment. These existing BMPs include seven ponds, seven rainwater gardens, three swirl separators and five infiltration pipes.

Since it wasn't clear how well these BMPs have been maintained and the watershed mapping did not delineate the direct drainage areas tributary to each practice, the updated P8 watershed modeling did not account for treatment for these BMPs (Barr, 2017). However, a sensitivity analysis was performed with the lake water quality modeling to evaluate how much a 50 percent reduction in stormwater total phosphorus loading (similar to what would be expected with widespread BMP implementation) during 2016 would influence the respective lake concentrations. Management actions were evaluated for the 2016 and 2011 conditions in East Goose Lake, as they represented wet and dry years, respectively (see Section 2.2).

In discussing the existing watershed BMPs (see Figure 1-1) with White Bear Lake staff it was understood that some of the practices may not have been inspected and/or maintained on a regular basis, or were in-need of more documentation for maintenance activities (Barr, 2017). However, this past summer, a maintenance agreement was established for the rainwater gardens along County Road F in that the County hired an MCC crew to maintain the plantings and clean out the inlets. Future work will likely include weeding, trash removal, addition of mulch, supplemental plantings and replacement of the inlets, where necessary. Similarly, it is recommended that MS4 and VLAWMO staff coordinate to document inspections and maintenance of all existing watershed BMPs. Depending on existing BMP performance, it can be used to adapt future maintenance activities and inform or change the priority for implementing some of the BMPs identified in Section 4.

Based on an evaluation of the GIS mapping (see Figure 1-1), it is estimated that two-thirds of the East Goose Lake watershed is currently receiving stormwater treatment of the runoff phosphorus loading on an annual basis, while approximately 40 percent of the West Goose Lake watershed is receiving stormwater treatment.

### 2.1.2 Past In-Lake Treatment Measures and Aquatic Invasive Species Control

Other in-lake treatment measures completed within the past 15 years included the removal of nearly 19,000 pounds of bullheads from Goose Lake between 2012 and 2015, as well as ongoing herbicide spot treatments in West Goose Lake. An updated fish survey (Blue Water Science, 2017) indicates that commercial fishing successfully reduced bullhead densities and no other fish management is needed at this time. In addition, common carp were not observed during the fish survey.

Goose Lake had the lowest diversity of aquatic plant species relative to the other lakes surveyed for the TMDL study (Wenck, 2014a). VLAWMO staff identified only three species in each basin of the lake: narrowleaf pondweed and elodea (Canada waterweed). In East Goose Lake, plants were found along the shoreline edges of the Lake. In West Goose Lake plants were found throughout the lake, but consisted mostly of elodea, which was mostly concentrated along the eastern edge connecting to East Goose.

## 2.2 East Goose Lake

Updated lake and watershed modeling was developed for this study and optimized to reproduce the observed water quality for each lake during the summer periods of interest. Figure 2-1 shows how the predicted and measured total phosphorus concentrations compare during the summer of 2016 for East Goose Lake. Approximately 85 percent of the phosphorus load was attributed to sediment phosphorus release during this time period. As a result, Figure 2-1 also shows that the predicted phosphorus concentration in East Goose Lake would be much more sensitive to an 80 percent reduction in internal load (similar to what would be expected following an in-lake alum treatment) than it would have been in response to a 50 percent reduction in stormwater loading (similar to what would be expected with widespread BMP implementation) during 2016. It should also be noted that the results of these analyses are based on the same starting phosphorus concentration at the beginning of the summer. Over time, following full-scale BMP implementation or in-lake alum treatment, it is expected that the starting concentrations would be closer to the shallow lake standard at the beginning of each summer season. Based on the results shown in Figure 2-1, this in turn, should ensure that an in-lake alum treatment would maintain lake water quality at levels that would be consistent with the shallow lake standards.

**Figure 2-1 2016 Water Quality Modeling Results for East Goose Lake**

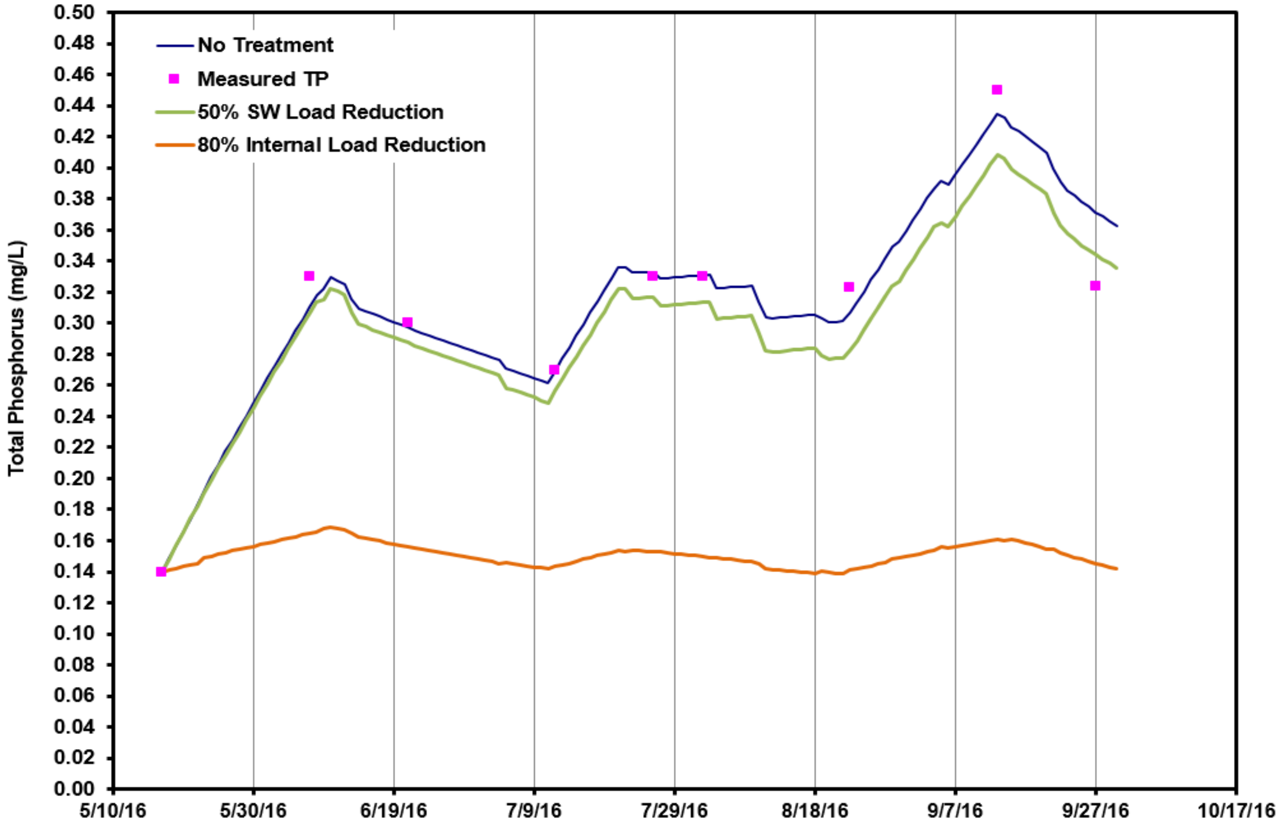
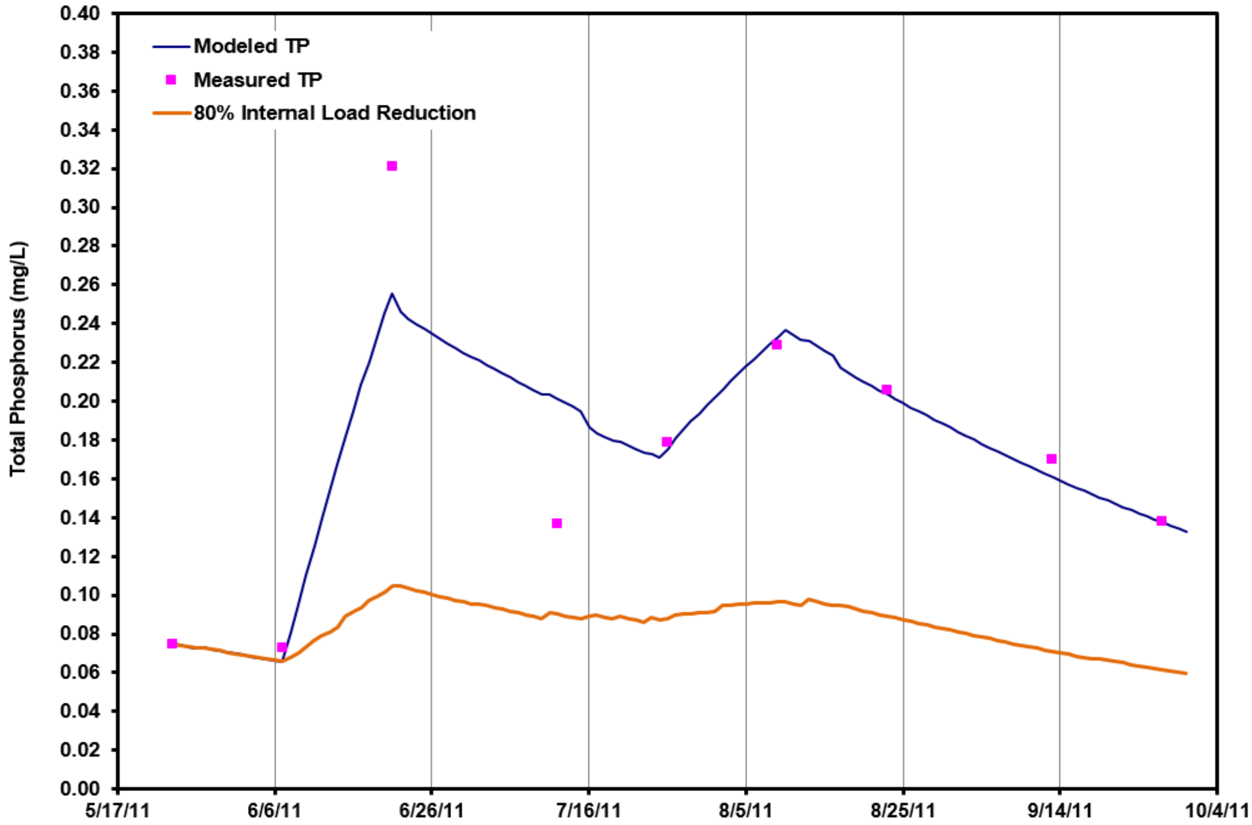


Figure 2-2 shows how the predicted and measured total phosphorus concentrations compare during the summer of 2011 for East Goose Lake. Approximately 80 percent of the phosphorus load was attributed to sediment phosphorus release during this time period. As a result, Figure 2-2 shows that the predicted phosphorus concentration in East Goose Lake would respond well to an 80 percent reduction in internal load (similar to what would be expected following an in-lake alum treatment) during 2011. Again, based on the results shown in Figure 2-2, an in-lake alum treatment would maintain lake water quality at levels that would be consistent with the shallow lake standards.

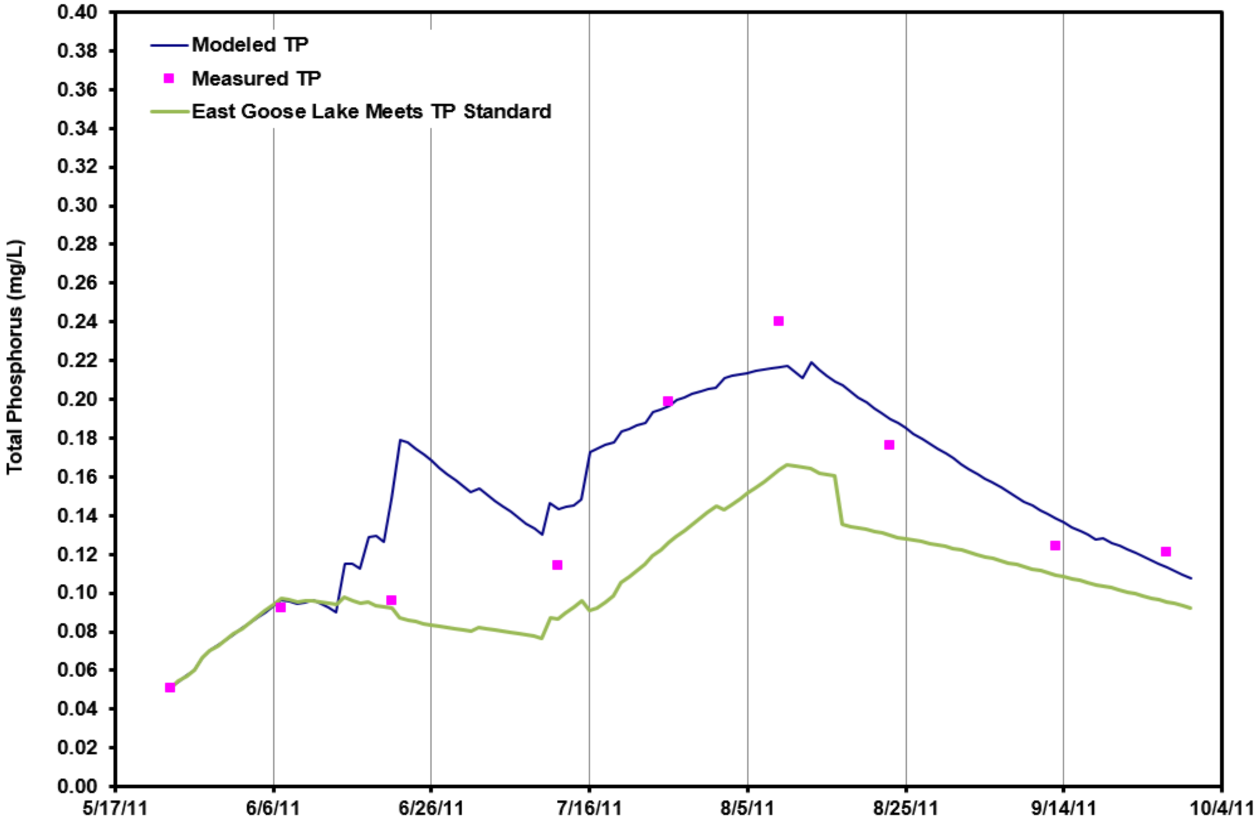
**Figure 2-2 2011 Water Quality Modeling Results for East Goose Lake**



## 2.3 West Goose Lake

Figure 2-3 shows how the predicted and measured total phosphorus concentrations compare during the summer of 2011 for West Goose Lake. Approximately 26 percent of the phosphorus load was attributed to sediment phosphorus release, 34 percent can be attributed to stormwater runoff and 39 percent to upstream contributions from East Goose Lake during this time period. As a result, Figure 2-3 also shows that the predicted phosphorus concentration in West Goose Lake is more sensitive to a reduction in incoming phosphorus concentration from East Goose Lake (similar to what would be expected if East Goose Lake had a phosphorus concentration that met the 60 µg/L standard) during 2011. An in-lake alum treatment is also recommended for West Goose Lake as the modeling results indicate that it would be needed to ensure that the water quality goals/standards are met on a consistent basis. Over time, following an in-lake alum treatment (and to a lesser extent, full-scale BMP implementation), it is expected that the concentrations would be maintained closer to the shallow lake standard throughout the summer season. This is confirmed by the fact that 65 percent of the phosphorus load to West Goose Lake is influenced by internal loading in both East and West Goose Lake.

**Figure 2-3 2011 Water Quality Modeling Results for West Goose Lake**



# 3.0 Social Implications of In-Lake Management

Understanding the inner working and prescribing management strategies of lake systems requires use of complex mathematical watershed and lake models. However, the resultant management strategies, although technically supported, are often difficult to convey to the public. To address the issue, a stakeholder engagement process was incorporated into the 2017 feasibility study (Barr, 2017). The goal of the stakeholder engagement process was to involve the public, regulatory agencies and VLAWMO staff in the process of identifying and vetting management solutions for each lake.

The 2016 Stakeholder Charrette was attended by members of the public, non-governmental organizations (Midwest Ski Otter Ski Club and North Oaks Homeowners Association), municipal agencies (Cities of North Oaks and White Bear Lake and Ramsey Conservation District), state government (Minnesota Department of Natural Resources and Minnesota Pollution Control Agency) and VLAWMO staff. The attendees convened for a state of the lake presentation for each lake followed by collaborative group discussions.

According to the groups, Goose Lake can support non-motorized activities, waterskiing, pontooning, and fishing for crappies and bass. The groups also acknowledged concerns about the absence of waterfowl and bald eagles, and the presence of curlyleaf pondweed. In addition to the concerns acknowledged, they also thought plant herbicides or harvesting warranted further investigation, as well as the correlation between bullhead removal and improvements in water quality and clarity, and whether water skiing and aquatic plants can coexist in Goose Lake.

When group attendees were asked about what role fish and aquatic plants play they were interested in discerning the difference between invasive and non-invasive plants. It was noted that the lakes have curlyleaf pondweed and Eurasian water milfoil edging into East Goose Lake from the southwest corner. Also, there was concern about the lack of species diversity and how that would affect the ecological functions of the lakes. They were also interested in an evaluation of the following:

- Investigating how fish and plants interact within the lake system and the possibility of using alum treatment on all or part of East Goose Lake;
- Encouraging recreational use in one of the Goose Lake basins. VLAWMO will address restricted boating through educational efforts.

Based on follow-up discussion with staff from State agencies and Board members, it was recommended (Barr, 2017) that VLAWMO complete a Lake Vegetation Management Plan (LVMP) and further evaluate in-lake management practices (see Section 4).

A follow-up stakeholder meeting held July 2018 discussed the results of the various reports.  Direction for future action: Proceed with grant application for alum treatment. This is justified by the findings from the feasibility study that internal treatment is both more cost-effective and more relevant for the unique circumstances surrounding Goose Lake.  The alum treatment will need a complementary vegetation management plan to address vegetation changes. See Section 4.2.3.

# 4.0 Summary

## 4.1 Potential Improvement Options

As discussed in Section 2.1, and shown in Figure 1-1, there are several existing BMPs in the East and West Goose Lake watershed. An evaluation of the storm sewer conveyances that did not have any existing stormwater treatment revealed that there are approximately five high-priority watershed locations where BMPs should be considered for implementation.

Table 4-1 provides rough estimates of planning level construction costs for the respective watershed BMPs at the recommended BMP locations, based on experience with similar practices in Metro lake watersheds. The annual load reductions expected for the watershed practices were estimated with the P8 model. The cost-effectiveness values in the table should be comparable as it is expected that these options will experience similar lifespans and/or timeframes for significant levels of operation and maintenance.

**Table 4-1 Summary of Water Quality Improvement Options**

| Water Quality Improvement Option | Estimated Annual TP Reduction (lbs/yr) | Opinion of Potential Costs | Annual Cost per Pound TP Removed ($/lb) |
|---|---|---|---|
| Option 1—Retrofit Lake Bay for Improved Stormwater Treatment | 10 | $100,000 | $10,000 |
| Option 2—Construct Off-Line Filtration System for Low Flows | 25 | $300,000 | $12,000 |
| Option 3—Construct Pond On-Line With 36”-dia. Storm Sewer | 25 | $300,000 | $12,000 |
| Option 4—Infiltration Pipe Upstream of Storm Sewer Outfall to East Goose Lake | 5 | $50,000 | $10,000 |
| Option 5—Infiltration Pipe on School Property | 25 | $100,000 | $4,000 |
| Option 6—Alum Treatment of West Goose Lake | 100 | $55,000 | $550 |
| Option 7—Alum Treatment of East Goose Lake | 800 | $170,000 | $213 |

It is expected that wider-scale implementation of rainwater gardens throughout the watershed would be more cost-effective than the other watershed BMPs shown in Table 4-1, but they may not be feasible and would likely need to be implemented as a part of street reconstruction projects to realize significant cost savings. It is also expected that the alum treatment costs for Options 6 and 7 will be closer to the values shown, assuming that both basins are treated at the same time, as they reflect the current collection and analysis of additional sediment cores across each lake surface for phosphorus fractionations and dose determinations. Table 4-1 confirms that in-lake alum treatment is significantly more cost-effective than the available watershed BMPs. Other than herbicide treatments and bullhead removal between 2012 and 2015, which successfully controlled the rough fish densities (Blue Water Science, 2017) but did not result in measurable changes to lake water quality, no other in-lake treatment alternatives were considered to be cost-effective and/or adequate to meet the water quality goals for the lakes.

## 4.2 Recommendations

### 4.2.1 Alum Treatment for East and West Goose Lakes

The application of aluminum has two expected mechanisms: (1) aluminum binds with iron-bound phosphorus in the sediment, thereby forming Al-P, and (2) a residual amount of unbound aluminum remains in the sediment and is available to bind phosphorus that is released from the decay of Org-P. For most lake systems alum dosing is designed to provide some amount of "excess" aluminum to bind phosphorus released from decayed Org-P. However, the aluminum added to the sediment will age over time and be less effective at capturing more phosphorus. Due to the high amount of Org-P in East Goose Lake and West Goose Lake sediment, it is recommended that the alum treatments of East Goose Lake and West Goose Lake be split into two applications separated by a few years or more in order to capture more of the Org-P in the sediment as it decays over time. By splitting the alum treatment into two applications separated by two or more years, more of the decomposing Org-P can be captured by the alum.

Two forms of aluminum are typically applied to lakes: alum and sodium aluminate. When alum is added to a lake, it will lower the pH (make it more acidic), while sodium aluminate will raise the pH (more basic). Therefore, these two chemicals are often added in combination to neutralize the pH effects during treatment. At lower doses, alum-only applications can be conducted without adversely affecting the pH (i.e. pH stays above 6). Alum is typically less expensive and easier to work with than sodium aluminate, and an alum-only treatment may be preferable when it will not cause an unacceptable change in pH. Alkalinity and pH were tested in each of the waterbodies on October 25, 2017. A higher alkalinity indicates a lake is more resistant to a change in pH from an alum treatment. East Goose Lake had the lowest alkalinity, and would therefore be most susceptible to a pH change from the addition of alum. A chemical model called PHREEQC was used to model the pH change from the prescribed alum dose to East Goose Lake; model inputs included the measured pH and alkalinity, and the prescribed alum dose. The model demonstrated that the pH would remain above 6.0 with an alum treatment only for the individual alum applications prescribed in Table 4-2. A minimal pH target of 6.0 will minimize the risk of adversely affecting aquatic life and ensure that aluminum hydroxide floc ($Al[OH]_3$) will form readily and settle quickly.

**Table 4-2 Recommended Alum Dosing for Split Applications**

| Lake | First Application | | Second Application | | Total | |
|---|---|---|---|---|---|---|
| | gallons alum/acre | gallons alum | gallons alum/acre | gallons alum | gallons alum/acre | gallons alum |
| East Goose | 288 | 27,329 | 288 | 27,329 | 575 | 54,658 |
| West Goose | 346 | 5,887 | 346 | 5,887 | 693 | 11,774 |

Alum is typically less expensive and easier to apply than a combined application of alum and sodium aluminate; therefore, it is recommended that alum-only treatments be utilized for East Goose and West Goose Lakes for the alum doses described in Table 4-2. The pH in the waterbody must be closely monitored during alum applications, and if the pH reaches the critical value of 6.0, the treatment should be stopped until the pH can recover. If pH and alkalinity conditions are different at the time of treatment and show a greater potential to lower pH below 6.0 during treatment, the treatment plan could be altered to replace a portion of the alum with sodium aluminate in order to buffer the pH.

Barr recommends that the alum treatments of East Goose Lake and West Goose Lake be split into two applications in order to capture more of the Org-P in the sediment that will decay over time. The second application would occur two or more years after the first application. Each alum-only application would be at a low enough dose that the lake’s pH would not be expected to lower below the threshold of 6.0, eliminating the need for a combined alum and sodium aluminate application. The recommended alum doses for East Goose Lake and West Goose Lake are summarized in Table 4-2.

Splitting the alum treatment into multiple applications would also allow for adjustments to the final alum dose, based on observations of water quality and/or sediment chemistry following the first application. The total estimated costs (including engineering and treatment oversight) for the recommended split application of alum to each lake are shown in Table 4-1. Typically, in-lake alum treatments are effective for 15 to 20 years, with shallow lakes experiencing shorter durations of effectiveness, depending on the extent of watershed treatment. However, it is expected that the split applications of alum, combined with the extent of stormwater treatment in the East Goose Lake watershed, will ensure that the effective life of the alum treatment is greater than ten years and would likely approach 15 years. VLAWMO will be responsible for any future maintenance that will be needed to achieve the effective life of the project.

### 4.2.2 Spent Lime for Internal Load Control in Oak Knoll Pond

Barr (1992) previously demonstrated the potential use of spent lime sludge from water treatment operations as a bottom sealer to prevent phosphorus release from anoxic sediments collected from Goose Lake. The study used a sediment/water microcosm approach that showed that various small doses of spent lime were capable of completely controlling sediment phosphorus release under anoxic conditions. Since these experiments were conducted, Barr has demonstrated the efficacy of using spent lime to treat phosphorus and solids in stormwater runoff, but in-lake treatment for sediment phosphorus control has not been attempted outside of the lab setting. Since a significant portion of the cost of in-lake alum treatment is associated with the chemical costs, it is worth considering alternatives such as spent lime, which is a byproduct of water treatment operations that currently incurs significant expense for disposal by local utilities.

It is recommended that VLAWMO initiate a study, in cooperation with Barr, to evaluate pilot-scale implementation of this treatment approach in Oak Knoll Pond as well as development of the conceptual design and potential cost-effectiveness for full-scale implementation of in-lake treatment for any other watershed basins that are currently experiencing high levels of sediment phosphorus release. The recommended study objectives would include assessments of spent lime availability and transportation costs, savings in comparison with current disposal methods, the equipment needs and costs for surface water applications including both filter cake and slurry forms of spent lime, and assessments of sediment and surface water quality improvements as well as the overall life-cycle cost-effectiveness for comparison with other in-lake treatment options. It is expected that the consulting costs for this pilot-scale study could range from $15,000 to $30,000, depending on the treatment extent and monitoring requirements.

### 4.2.3 Lake Vegetation Management Plan (LVMP)

A lake vegetation management plan (LVMP) is a document the Minnesota Department of Natural Resources (DNR) develops with public input to address aquatic plant issues on a lake. The LVMP is intended to balance riparian property owner’s interest in the use of shoreland and access to the lake with preservation of aquatic plants, which is important to the lake’s ecological health. It is recommended that VLAWMO work with the DNR and the public to develop a LVMP for both East and West Goose Lakes that will prescribe the permitted aquatic plant management actions (mechanical and/or herbicides) for a five-year period, including controls for invasive plants and restoration of lake shore habitat. VLAWMO contracted the Ramsey Conservation District to perform an aquatic vegetation survey in 2014. VLAWMO will submit this survey to the DNR and inquire about whether the survey information can be used as the control for future plant management actions, or if further data collection is necessary.

VLAWMO staff has contacted DNR staff to determine next steps to create the LVMP. The Ski Otters and other stakeholders have indicated a willingness to be part of a task force to develop the LVMP. More fieldwork could be done in 2019, if needed. Documenting the invasive curly leaf pondweed will be done in the 2019 season. The Ski Otters have chemically treated the curly leaf population since 2008 using Aquathall. One year they tried harvesting with the Birch Lake harvesting machine but were concerned about vegetative spreading of the AIS. The task force of interested stakeholders could work over 2018-2019.

# 5.0 References

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